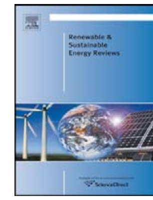
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Power generation from MSW of Haridwar city: A feasibility study

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ABSTRACT

Energy plays significant role in the development of a nation. The conventional sources, though exhausting and not environment friendly are being increasingly used. Looking at limited supplies and various environment problems associated with its uses, renewable energy sources are getting attention.

Municipal solid waste [MSW] is getting importance in recent years. Having fewer disposal problems is being considered as valuable bio-energy resources. The MSW management involves collection, transportation, handling and conversion to energy by biological and thermal routes.

The present paper reports the results of physical, proximate and TGA/DTA analysis, used to select the most appropriate method of energy conversion. Based on the energy potential available, the feasibility of energy conversion through biogas production using available waste has been carried out. The CDM benefits have also been considered. The cost of generation with and without CDM benefits is Rs. 1.36/- and Rs. 1.41/- per kWh respectively as compared to cost of energy from grid [Rs. 3.50/- per kWh]. Therefore power generation from MSW of Haridwar city using biomethanation conversion technology is feasible.

Contents

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1. Introduction and literature review

1.1. General

Energy is the primary and most universal measure of all kind of works performed by human beings and nature. Every thing what happens in the world is the expression of flow of energy. It is one of the main sources for the advancement of human civilization and is required for every activity and therefore plays a vital role in the development of society. Rapid industrialization, development of various transport system, comforts of living, growth of vast commercial complexes, community services etc become possible due to energy.

The energy sources available is divided into three types [1]

[a] **Primary energy sources.** Primary energy sources can be defined as the sources which provide a net supply of energy. Coal, oil, uranium, etc are the example of these types. The energy required to obtain these fuels is much less than what they produce by combustion or nuclear reaction. Their energy yield ratio is very high. The yield ratio is defined as the energy fed back by the material to the energy received from the environment. The primary fuel only can accelerate growth but their supply is limited.

[b] **Secondary energy sources**. These fuels produce no net energy. Though it may be necessary for the economy, these may not yield net energy. Intensive agricultural is an example wherein terms of energy the yield is less than the input.

[c] **Supplementary sources**. These are defined as those whose net energy yield is zero and those require highest investment in terms of energy. Insulation [thermal] is an example of these types of sources

The Energy consumption pattern of world, developed and developing countries as shown in Figs. 1–3 indicates that the consumption of coal and oil in the world is 27% and 39% of the total energy consumed respectively, 28% coal and 45% oil in developed

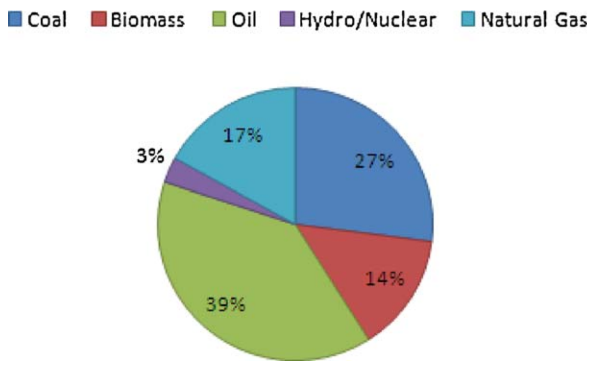


Fig. 1. Energy consumption pattern for the world [2].

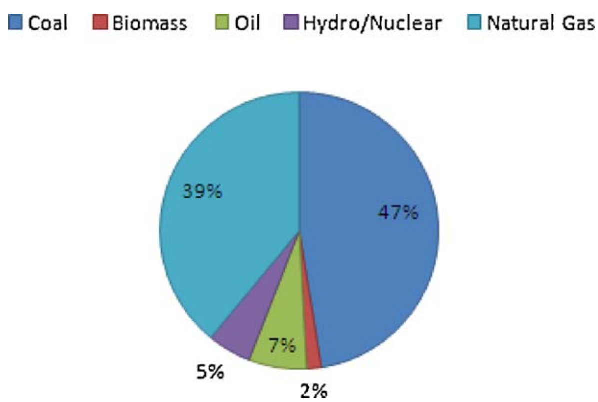


Fig. 2. Energy consumption pattern for developed countries [2].

countries like USA, UK, etc. The energy consumption pattern shows that 3% of the total energy is met by biomass by world while 97% by fossil and conventional energy resulting in the overall natural calamities and competition for energy [2]. Likewise, the developed countries meet their 99% energy needs from fossil and conventional energy and 1% from biomass resources. This indicates that developed countries, being rich, has high per capita energy consumption [e.g. USA 8000 kWh/year] and is responsible for causing major environmental consequences. On the other hand, the developing countries do not have purchasing power and do not have enough money to purchase costly fuels and therefore are forced to draw 43% of their energy from biomass available freely. As a result, the per capita energy consumption in developing countries is low [India: 150 kWh/year] [Annual report, MNRE [2008–2009]. The reasons for low per capita energy consumption in developing countries may be attributed to low income and low purchasing power and tendency to get the fuel free of cost. This led

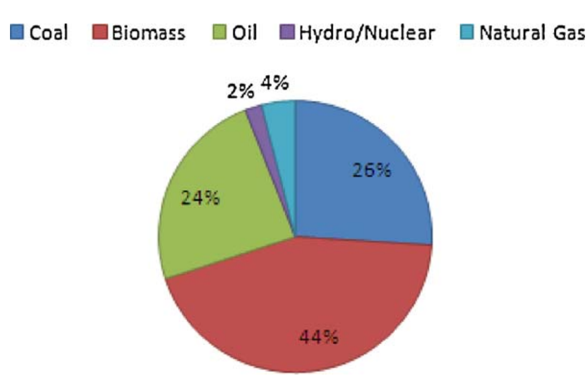


Fig. 3. Energy consumption pattern for developing countries [2].

to the deforestation of valuable natural forest to meet their fuel wood and timber requirement.

Consequently, the consumption and utilization of energy is considered as one of the important parameter to judge the standard of living, social and economic conditions, cultural values and degree of industrialization of a given region of the world. These aspects are characterized by the term “per capita energy consumption” which is directly related with the level of standard of living and can be expressed by per capita gross product, which plays significant role in economic development if a country. The energy serves three purposes:

1. To improve agricultural productivity
2. To improve the basic living environment.
3. To establish and sustain the industries.

The spurt in energy crisis due to the oil embargo of the 1970s has forced the countries of the world to take serious measures with regards to the energy consumption. The problem is further aggravated by the fact that available fossil fuels are exhaust able and depleting rapidly. This, coupled with environmental consequences of its utilization, has initiated the search for non-conventional/renewable energy sources, which have not only abundant availability but are also eco-friendly. The basic impact of this energy scenario is seen in rural areas which are facing shortage of fossil fuel as well as due to their remoteness.

The world energy resources and fossil fuel reserves are shown in Tables 1–3. The data in the table shows that availability of coal is large as compared to petroleum, natural gas and nuclear energy. The life of these fuels as also limited at present rate of consumption and before these fuels exhausted, the conservation and energy efficiency measures in existing applications and a search for alternatives to fuels needs to be made on significant level. It is indicative of the fact that well developed advanced renewable energy technologies are necessary to be made available before these fossil fuels are exhausted and should be available at competitive prices.

1.2. Energy sources and their availability

In the following Tables 1–3 country wise fossil fuel reserves as on 2006 is shown.

Table 1
Country wise oil reserve (billion barrels) [3].

Country	Oil reserves
Saudi Arabia	264.3
Canada	178.8
Iran	132.5
Iraq	115.0
Kuwait	101.5
UAE	97.8
Venezuela	79.7
Russia	60.0
Libya	39.1
Nigeria	35.9
United States	21.4
China	18.3
Qatar	15.2
Mexico	12.9
Algeria	11.4
Brazil	11.2
Kazakhstan	9.0
Norway	7.7
Azerbaijan	7.0
India	5.8
Rest of World	68.1
World Total	1,292.5

Table 2
World natural gas reserves by country [3].

Country	Reserves (trillion cubic feet)	Percent of world total
World	6112	100.0
Russia	1680	27.5
Iran	971	15.9
Qatar	911	14.9
Saudi Arabia	241	3.9
United Arab Emirates	214	3.5
United States	193	3.1
Nigeria	185	3.0
Algeria	161	2.6
Venezuela	151	2.5
Iraq	112	1.8
Indonesia	98	1.6
Norway	84	1.4
Malaysia	75	1.2
Turkmenistan	71	1.2
Uzbekistan	66	1.1
Kazakhstan	65	1.1
Netherlands	62	1.0
Egypt	59	1.0
Canada	57	0.9
Kuwait	56	0.9
Rest of World	602	9.8

Table 3
World recoverable coal reserves (billion tonne) [3].

Region/Country	Bituminous and anthracite	Sub bituminous	Lignite	Total
World Total	530.4	297.0	173.4	1,000.9
United States	125.4	109.3	36.0	270.7
Russia	54.1	107.4	11.5	173.1
China	68.6	37.1	20.5	126.2
India	99.3	0.0	2.6	101.9
Other Non-OECD Europe and Eurasia	50.1	18.7	31.3	100.1
Australia and New Zealand	42.6	2.7	41.9	87.2
Africa	55.3	0.2	-	55.5
OECD Europe	19.5	0.2	18.8	43.3
Other Non-OECD Asia	1.4	2.0	8.1	11.5
Brazil	0.0	2.0	0.0	11.1
Other Central and South America	8.5	2.2	0.1	10.8
Canada	3.8	1.0	2.5	7.3
Others	1.8	0.4	0.1	2.3

As it is clear from Table 1, the world total oil reserve is around 1,292.5 billion barrels. Saudi Arabia has the largest reserve of oil all over world. It constitutes about 20% of the total world oil reserves while India has only 0.5% of the total world oil reserves.

Table 2 shows the natural gas reserve for different countries as on November 2006. The world total natural gas reserve is around 6112 trillion cubic feet. It is clear from the table that Russia has the largest reserve of natural gas, which is around 28% of the total world natural gas reserve while USA has only 3% of the total world natural gas.

Table 3 shows the coal reserve in different countries. The total world coal reserve is around 1000.9 billion tonne. As it is clear from the table United States has largest reserve of coal which is around 27% of the total world coal reserves. On the other hand, India has around 17% of the total coal reserves.

As mentioned in Table 4 that fossil fuel is depleting at faster rate and fossil fuel reserves are finite. The increasing population and excessive pressure for food, fuel and fodder on agriculture and other consumption sector have compelled rural population to depend on natural forests and agricultural waste for meeting their increasing demands. As a result, the deforestation and the resulting ecological imbalance have been adversely affecting the climatic and productive systems. The limited supply, increasing consumption and environmental consequence of the utilization of fossil fuel has initiated the search for alternative renewable energy sources.

Table 4
Life of fossil fuels (years) [4].

Fossil fuels	Life of the reserves (years)
Coal	210
Oil	42
Natural gas	60

1.3. Renewable energy

Since the renewable can be produced in a decentralized manner, it can help to overcome the problems of distribution associated with conventional sources of energy, especially, in remote rural areas.

Renewable energy sources include both direct solar radiation by collectors [e.g. solar and flat-plat thermal cells] and indirect solar energy such as wind, hydropower, ocean energy and biomass resources that can be managed in a sustainable manner. Traditional methods of using biomass and derivatives such as wood and charcoal are highly inefficient, in contrast with modern techniques emphasing proper forest management sustained-yield fuel wood plantations and efficient production.

If broadly interpreted, the definition of renewable resources also includes the chemical energy stored in food and non-fuel plant products. From an operational viewpoint, the correct way to treat renewable energy is as measure to reduce the demand for conventional energy forms.

1.3.1. Renewable energy sources

1.3.1.1. Small hydro power. Small hydro installations were cheaper to run but expansive to build expansive to build. The concept is changing now with smaller, lighter and high-speed turbine equipment, low cost electronic speed and load control systems and inexpensive plastic penstock. Capital investment in SHP is still higher than in diesel generating system of comparable capacity have the long life and low operating costs which make it an attractive option for many applications. Small hydroelectric system provides clean, cheap electricity for local applications. Small-scale system captures the energy of flowing water and converts it to electricity. Although the potential of small hydroelectric system depends on the availability of water flow, where the resource exists it can provide cheap, clean, reliable electricity. Small hydropower, [up to 25 MW] with its multiple advantage as a decentralized, low cost and reliable form of energy, is getting the top priority in several countries including India in order to achieve energy self sufficiency.

Small hydro power is attracting great deal of attention as eco-friendly renewable energy source and offers many advantages including major social ones. It is available dispersed in remote areas away from the main centre of population and so it is the convenient source for giving electricity benefits to the isolated small communities. India has power potential of 15,000 MW [5] and the country has achieved 1694 MW [5] of power generated up to December 2004.

Micro-hydro power [MHP], the small-scale power generation, has been getting new fillip in recent years as it can play a key role in the development of rural areas, especially hilly areas. Micro-hydro scheme can provide power for industrial, agricultural and domestic uses in the form of mechanical or electricity. For hilly or remote areas, where the grid supply is not available, it becomes desirable to develop much low capacity stations.

1.3.1.2. Solar energy. The sun is the ultimate significant source of energy on the earth derives all hydrological process of evaporation, transpiration and snow ablation, as well as photosynthesis process. Direct beam radiation varies with time of the day and atmospheric condition.

India receives abundant sunshine with about 1648–2108 kWh/m^2/year with nearly 250–300 days of useful sunshine in a year. The daily solar energy incident is between 5 and 7 kWh/m^2 at different locations. These are converted into other forms of energy through thermal or photovoltaic conversion routes [6].

Solar energy is received on earth in intermittent and dilute form with very low power density from 0 to 1 kW/m^2. The SPV potential is about 20 MW/km^2. Thus solar energy applications are quite diverse ranging from power generation using thermodynamic cycles to direct conversion to electricity using solar photovoltaic [SPV].

1.3.1.3. Wind energy. Wind energy can be converted into mechanical energy by wind turbine. For the installation of large, high-speed windmills; wind characteristics data of the location is required. In India the mean win speeds in the different region ranges from 12 to 20 km/h and the wind energy averages 210–650 kWh/m^2/year along the coastal [7].

Two types of systems viz. wind mill pumps for irrigation and wind electric generators [aero generators] systems to generate electricity are used. The later is visible in inaccessible areas for small applications and where extension of grid or supply of prohibitive proposition. The total wind energy is estimated to be about 3045 kWh or about 0.2% of the solar energy received by the earth. The technically usable potential is reported to be 30 trillion kWh per year, which is about 35% of the current world total energy consumption. It is important to mention that the power output from the windmill varies with the cube if the wind speed is consequent, windy location on mountains and coasts are only suitable for feasible generation of electricity. Wind electric generators are suitable as an independent power source or for augmenting the electricity supply form grids. The extent to which the wind can be exploited depends on the probability density of occurrence of different speeds. The annual wind speed at different location is an indicator of the wind resources. The relationship between annual wind mean speed and potential of the wind energy resources as given in Table 5 shows hat exploited wind speed are in the range of 4.5–6.7 m/s.

Out of total potential of 45,000 MW, about 1870 MW has been exploited so far [5]. The cost of unit power generation from wind has been reported to be lower than diesel power and is comparable to thermal power. The efforts are underway to increase long-term reliability, reduce maintenance cost, and improve good efficiency of the system [http://www.mnes.nic.in].

Wind energy has proved to be an economical competitively renewable energy sources in certain locations in India, which are as follows:

1. Coastal regions in Gujarat, Kachchh, Saurashtra.
2. Gaps in eastern Ghat in Tamil Nadu, Tuticorin, Kayathar.
3. Plains in Rajasthan, U.P. and
4. Hill tops in Uttaranchal, M.P.

Table 5
Wind resources as per wind speed [8].

SN.	Annual mean wind speed @ 10 m height	Indicated value of wind resources
1	<4.5 m/s	Poor
2	4.5–5.4 m/s	Marginal
3	5.4–6.7 m/s	Good to very good
4	>6.7 m/s	Exceptional

In Uttarakhand, modest wind potential is available. The mean annual wind speed and wind potential in the area is 1.25 km/year and 215 kWh/m^2/year respectively.

1.3.1.4. Biomass energy. Biomass, a product of photosynthesis, includes all new plant growth, residues and wastes such as rotation trees, herbaceous plants, fresh water and marine algae, aquatic plants, agricultural and forest residues, kitchen and city garbage, night soil, sewage etc. furthermore, biodegradable organic effluents from canneries, sugar mills, slaughterhouse, meat packing factories, breweries, distillers, etc. are also categorized as biomass resources. To meet the growing demand of energy, it is necessary to focus on efficient production and use of biomass resources to meet both traditional and high energy demand. The biomass production for fuel, food, fiber and fodder, requires sustainable land use and integrated planning approaches at all levels in the country. The proper selection of site and tree plants species suitable to different agro-climatic conditions can open new avenues for integrated land use planning and land management for the production of maximum biomass in minimum time at low cost. Such strategies allow synergistic increase in food crop yield and decrease fertilizer applications, while providing local source of energy and employment. The estimated potential of various biomass resources is: Biomass energy 17,000 MW, Co-generation 8000 MW and energy from waste [MSW, etc] 1000 MW [9].

Utilization of biomass for power generation is handicapped due to its production being labor intensive, and scattered availability, seasonal availability, localized price sensitivity and lack of automatic feed control, tedious handling, besides having the high moisture, low energy and low bulk density [30–180 kg/m^3] needing substantial transportation cost. A wide variety conversion technology can be used to produce energy from biomass. Some are simple and some are well developed, while others are at different stages of development. The choice of particular process is determined by the number of factors such as location of resources, its physical condition, the economics of compacting processes and the availability of sustainable market for the product. Technologies to convert biomass to energy come under two categories:

1. Biological process:
   [a] Anaerobic digestion
   [b] Fermentation
2. Thermo chemical process:
   [a] Combustion
   [b] Pyrolysis
   [c] Gasification
   [d] Liquefaction.

Out of these processes, only two viz. [a] anaerobic digestion and [b] biomass gasification will be considered as the processes for the production of biogas and producer gas as gaseous fuels.

1.3.1.5. Tidal energy. Tides are periodic rise and fall of the water level of sea due to gravitational forces of the moon and sun on the ocean water of the earth, spinning of earth around its axis and their relative positions. The first attempt to utilize energy of ocean was made in the form of tidal mills in 11th century in Great Britain and late in France and Spain. Japan has installed a floating type tidal power generation at Kaimei in Yira, Tsuruoka city [6]. The possible sites for tidal power generation in India are of Gulf of Combay, Gulf of Kutch south Hoogly River. A preliminary study undertaken by central public water department [CPWD] for tidal station in the Gulf of Combay has claimed that energy generated by tides is costlier than energy obtained from commercial sources. The world tidal energy potential is 3,000,000 MW, where as it is about 15,000 MW in India [5]. The potential of few sites worthy of

Table 6
Tidal power plants in India [10].

SN.	Name of site	Maximum tidal range (m)	Average tidal range (m)	Tidal power potential (MW)
1	Gulf of Combay	11	6.77	7000
2	Gulf of Kutch	8	5.23	1200
3	Ganga dalta of Sunderbans	5	2.77	100

consideration for tidal power development [TPD] are given in Table 6

The large-scale tidal power generation is in a dormant state but is expected to be the major source of power supply and provide benefit to a large number of reote islands and their inhabitants who are without electricity. Tidal energy conversion schemes are identified by the number of basins [pools] and the operating modes of turbine-generator. The most common tidal schemes are:

1. Single basin schemes
2. Modified single effect schemes.
3. Multiple basin schemes and
4. Pumped storage schemes.

1.3.1.6. Geothermal energy. It is the thermal energy contained in the interior of the earth. The total world's installed geothermal production is only 6000 MW while the world's potential is about 62,500 MW [white 1995]. The geothermal energy in the form of steam and hot water are available along the West Coast, Ladakh, and parts of Himachal Pradesh. However no exact estimates of potential for generating electricity are available [5]. It can be used for power generation, space heating, extraction and refining of borax and sulfur, greenhouse heating and refrigeration and air conditioning, operation of geothermal pumps, hot water for springs. The temperature of geothermal water varies from place to place. Some sites can produce steam at temperature above 350 °C, while other produce water at temperature well below 100 °C. The higher temperature above 180 °C are typically used to generate electricity and the lower temperatures are used for heating applications At present, the work being done on geothermal energy consists of mushroom cultivation and poultry farming in the Ladakh region, two green house huts at the pugfa geothermal field for growing vegetables and poultry farming under controlled conditions, a 7.5 tonne capacity cold storage pilot plant installed at Manikaran, Himachal Pradesh and a 5 kW experimental power plant developed by Indian Institute of Science, Bangalore, Indian based on Rankin Cycle [10].

1.3.2. Significance of renewable energy

The advantages of renewable energy are that these can replace fossil and nuclear fuels, are eco-friendly, can't be turned off foreign power, have low gestation period, lower transportation and transmission cost and can be used to any scale of need.

Further the global parameters driving the movements for renewable and energy efficiency as a total of demand side management under clean development mechanism [CDM] obviates climatic changes, reduce pollution and ozone hole exigencies without sacrificing the energy security. Developing countries have additional energy availability for rural availability for rural subsistence as well as for development.

1.3.3. Status of renewable in India

India, being located in the tropical region, is endowed with the wast potential of renewable energy. It is for the forefront of harnessing renewable energy and is one of the largest programmes in the world. About 5508 MW of power is being generated from renewable energy which is over 7% of total installed capacity in the country. India with installed capacities of 2980 MW from wind energy, is the fifth energy in the world after Germany, USA, Spain and Denmark [11] A. Further small hydro is an important source and about 1694 MW has already been harnessed [5]. Solar energy is also estimated as 20 MW/km^2; about 1188 kWp [5.94%] of SPV has been harnessed while bagasse based co-generation plants provided 484 MW and 281 MW are under the progress. A capacity of 26 MW has so far been harnessed from urban and industrial wastes. A unique 140 MW Integrated Solar Combine Cycle [ISCC] power project is being planned to be set up at Mathania village near Jodhpur Rajasthan, which is the largest and first of its kind project in the world with production capacities of 50 MW from SPV, and 53 MW biomass gasifiers, has been proposed as stand-alone/off-grid electricity for decentralized applications [Project Monitor 2005]. Two plants based on solid municipal waste has been installed at Vijayawada, Andhra Pradesh and Mahboobnagar, Andhra Pradesh with capacities 6 MW and 6.6 MW respectively [12].

1.4. Introduction of MSW

Today, the world's population generates enormous amount of waste. Whether we live in industrilized countries or developing countries, in big or in small cities, or whether we are rich or poor, we all produce waste, for decades, industrial countries [ICs] have lived beyond these resources. Yesterday's belief that all resources were eternal has now changed. Waste minimization is a key concept in ICs. The amount of waste produced is dependent on the country, type of urban district, population, city size, culture, style of life and of course income.

However the question remains, how should waste be handled safely and economically? It may be easier that people should minimize the total amount of packaging and municipal solid waste in ICs where the waste production per person is very high but in DCs where generation per person already is low there is not much scope of reduction. In certain ordinary districts in the USA, each person generates 2.7 kg MSW daily, whereas in Pakistan approximately 0.5 kg waste per person, per day is generated. Some African countries generates less than that [as low as 0.2 kg per person, per day], i.e. only 10% of the amount produced in the USA on a per capita basis. How ever in many DCs there is a large difference between the consumption pattern of the rich and those of the poor. Based on this difference, people in high and medium income area can produce waste of the same magnitude as the average value for the industrilized World [13].

The municipal solid waste [MSW] industry has four components: recycling, composting, land filling, and combustion. The U.S. Environmental Protection Agency [USEPA] defines MSW to include durable goods, containers, packaging material, food wastes, yard wastes, and miscellaneous inorganic wastes from residential, commercial, institutional, and industrial sources. It excludes industrial waste, agricultural waste, sewage sludge, and all categories of hazardous wastes, including batteries and medical wastes [14].

In Fig. 4 the management chain of a city waste is shown.

Table 7 gives the population, quantity of waste generated/day and per capita waste generation in various cities of the country.

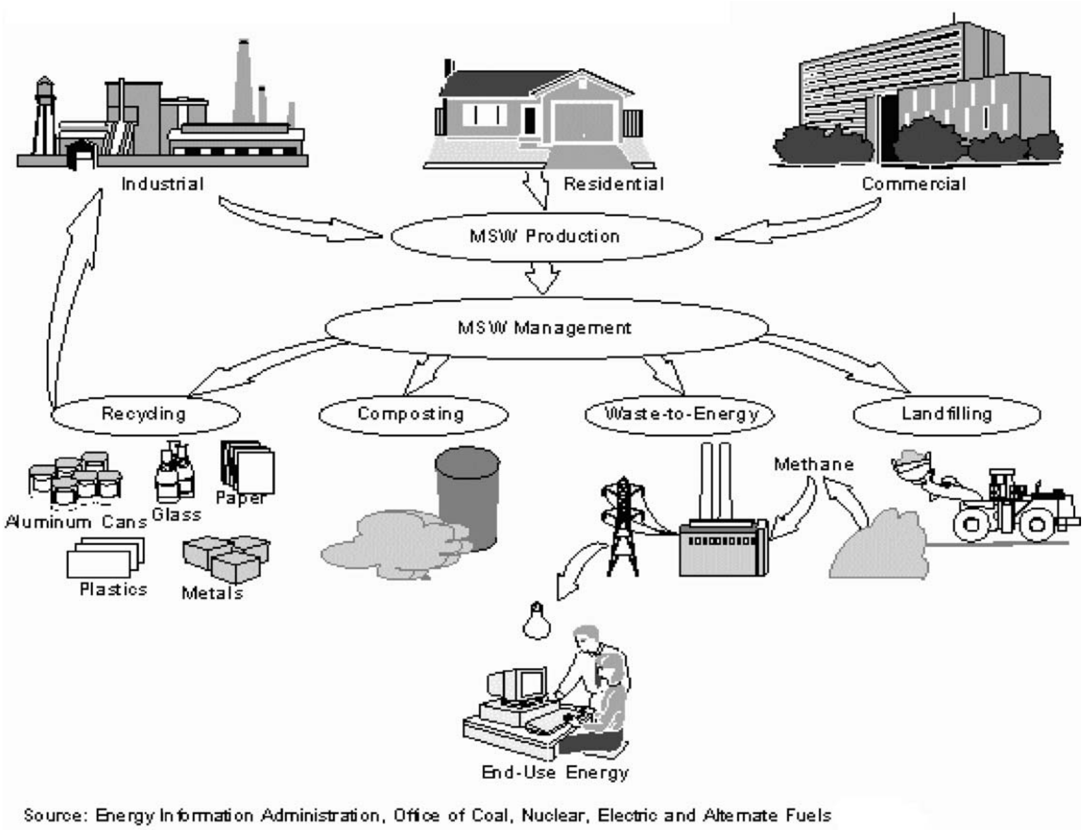


Fig. 4. MSW generation and management chain [15].

Table 7 shows the waste generated by different cities of India. As we can see that Dehradun generates MSW 131 tonne per day. Per capita MSW generation is 0.31 kg per day per capita. As the MSW data is taken from the municipal office of Haridwar the waste generated by Haridwar city is around 190 tonne per day and on an average basis the population of Haridwar is around 5 lakh. Therefore the MSW generated per day per capita is around 0.38, which is very near to the waste generated by Dehradun city.

1.5. Advantages of solid waste management

As the solid waste disposal is itself is a big problem but there are many ways to get profits by the proper management of the solid waste. As the solid waste contains a large variety of matter, by knowing the proper chemical composition and the characteristics of the MSW we can manage it properly and ultimately we can reduce the solid waste and the hazards on one hand while on the other hand we can get profit for the society. There are so many ways by which MSW can be managed depending on its chemical composition and are given as follows:

1.5.1. Recycling

Plastics are an important recyclable material in developing countries [DCs]. In many countries for example some scavengers start collecting plastics at early morning. At noon they start to wash the plastics and after drying it is sold to a dealer. Afterward, more plastics can be collected in the afternoon and in the evening, which means that they scavengers work 12–14 h per day. The plastic is sold by dealers to a local plant that usually shreds it or makes plastic granules. New plastics products such as litter bags and pipes are produced in many local and simple factories [14].

Paper is also recoverable material that ends up in the recycling industry. The biggest problems at paper mills that deal with recyclable paper are inherent impurities such as plastic, staples, stones and sand. The industry must have special processes and equipment to remove these from the paper before it is processed. Product like craft paper, card board or toilet paper are created. Paper can be recycled seven to eight times, each time, 22 trees are saved every tonne of recycled paper produced. In Brazil, 29% of paper is recycled which is comparable to the percentage recycled in many industrial countries [ICs] [14].

1.5.2. Composting

Over 60% of the municipal waste in DCs is organic in nature. The waste usually has high moisture content, largely as a function rainfall, especially if containers and bins are not covered. Such organic waste is suitable for composting. Waste compost has traditionally been used in DCs for soil improvement but attitude have changed due to the risk of contaminants entering the waste stream as a consequence of industrial development [14].

1.5.3. Incineration

Incineration is another method to dealing with waste in some cities in DCs. But as already stated, waste in DCs contains a large amount of organic house waste with high moisture content and low energy value. The installed capacity of incineration plants of India is 83 MW. [17]

1.5.4. Land filling

Dumping is the most common way of dealing with waste and land filling is probably the cheapest way to treat waste. Therefore,

Table 7
MSW generated by different cities per day per capita [16].

Name of city	Population (as per 2001 census)	Area (km^2)	Waste quantity (tonne/day)	Waste generated/capita/day
Kavaratti	10,119	4	3	0.3
Gangtok	29,354	15	13	0.44
Itanagar	35,022	22	12	0.34
Daman	35,770	7	15	0.42
Silvasa	50,463	17	16	0.32
Panjim	59,066	69	32	0.54
Kohima	77,030	30	13	0.17
Port Blair	99,984	18	76	0.76
Shillong	132,867	10	45	0.34
Shimla	142,555	20	39	0.27
Agartala	189,998	63	77	0.4
Gandhinagar	195,985	57	44	0.22
Dhanbad	199,258	24	77	0.39
Pondicherry	220,865	19	130	0.59
Imphal	221,492	34	43	0.19
Aizwal	228,280	117	57	0.25
Jammu	369,959	102	215	0.58
Dehradun	426,674	67	131	0.31
Asansol	475,439	127	207	0.44
Kochi	595,575	98	400	0.67
Raipur	605,747	56	184	0.3
Bhubaneshwer	648,032	1354	234	0.36
Thiruvanantapuram	744,983	142	171	0.23
Chandigarh	808,515	114	326	0.4
Guwahati	809,895	218	166	0.2
Ranchi	847,093	224	208	0.25
Vijayawada	851,282	58	374	0.44
Srinagar	898,440	341	428	0.48
Nmadurai	928,868	52	275	0.3
Coimbatore	930,882	107	530	0.57
Jabalpur	932,484	134	216	0.23
Amritsar	966,862	77	438	0.45
Rajkot	967,476	105	207	0.21
Allahabad	975,393	71	509	0.52
Visakhapatnam	982,904	110	584	0.59
Faridabad	1,055,938	216	448	0.42
Meerut	1,068,772	142	490	0.46
Nashik	1,077,236	269	200	0.19
Varanasi	1,091,918	80	425	0.39
Jamshedpur	1,104,713	64	338	0.31
Agra	1,275,135	140	654	0.51
Vadodara	1,306,227	240	357	0.27
Patna	1,366,444	107	511	0.37
Ludhiana	1,398,467	159	735	0.53
Bhopal	1,437,354	286	574	0.4
Indore	1,474,968	130	557	0.38
Nagpur	2,052,066	218	504	0.25
Lucknow	2,185,927	310	475	0.22
Jaipur	2,322,575	518	904	0.39
Surat	2,433,835	112	1000	0.41
Pune	2,538,473	244	1175	0.46
Kanpur	2,551,337	267	1100	0.43
Ahmedabad	3,520,085	191	1302	0.37
Hyderabad	3,843,585	169	2187	0.57
Bangalore	4,302,326	226	1669	0.39
Chennai	4,343,645	174	3036	0.62
Kolkata	4,572,876	187	2653	0.58
Delhi	10,306,452	1483	5922	0.57
Greater Mumbai	11,978,450	437	5320	0.45

upto 80% of the world practices open dumping or land filling. In India there are 2.5 million biogas plants are there and improved biomass stoves [improved chulhas] are 24 millions in numbers.[17]

1.6. MSW in Haridwar city

Haridwar is also a big generation city of MSW. The population of Haridwar city as per the census 2001 is 5 lakh. Haridwar is a holly place that's why it is difficult to say the exact population of Haridwar and the waste generation per day is 190 tonne per day [18]. The dumping site is Chandighat. So the per capita generation is around 0.38 kg per day. The materials contained by MSW are generally as follows:

A. Biodegradable waste:
1. Yard waste
2. Vegetable waste
3. Paper waste
4. Clothes [cotton]

B. Non-biodegradable waste:
5. Glass
6. Plastic

7. Thermacoal
8. Silt/ash/sand
9. Clothes
10. Boulders/stones
11. Leather

1.7. Scope of the project

The objective of the study is to analyze the MSW of Haridwar city chemically and suggest a energy conversion technology for managing that waste and to generate power from the waste in an efficient way and to prepare a feasibility report for power generation from the MSW of Haridwar city.

1.7.1. Work done

Energy from waste is not a new concept but it is a field, which requires a serious attention. There are various energy conversion technologies available to get energy from MSW but the selection is based on the physical and chemical properties of the waste. Therefore it is important to go for a detailed analysis of the MSW to choose a right technology.

The scope of present work is to study feasibility of power generation using MSW of Haridwar city. MSW samples were collected from dumping site of Haridwar city and analyzed in the laboratory for proximate analysis and TGA/DTA analysis to know the complete chemical characteristics of that waste and check its sustainability for conversion to energy. Based upon proximate analysis and energy triangle, the MSW falls in the category of biomethanation process followed by power generation using DG set.

2. Policies and incentives of ministry of new and renewable energy sources

2.1. MNRE policy

Wastes generated from Urban and Industrial sector increase continuously with rising population, rapid urbanization and industrialization. Some recent estimates have indicated that about 40 million tonne of solid waste and about 5000 million cubic meters of liquid waste is generated every year in the urban areas of the country. In addition to this, a large quantity of solid and liquid waste is also generated in the industrial sector. Most of the waste generated in the country finds its way into rivers, ponds, low lying areas outside the city, etc., without any treatment, resulting in odour, contamination of ground water and air as well as emission of Green House Gases like CH_4, CO_2, etc. This problem can be mitigate through adoption of environment friendly technologies for treatment and processing of waste before it is disposed of. These technologies not only lead to generation of a substantial quantity of decentralized energy but also reduce the quantity of waste besides improving the quality of waste to meet the pollution control standards. It is estimated that there is a potential of generating about 1500 MW of power from urban and municipal wastes and about 1000 MW from industrial wastes in the country, which is likely to increase further with economic development [12].

Ministry of New and Renewable Energy Sources is promoting setting up of Waste-to-Energy projects through National Programme on Energy Recovery from Urban and Industrial Wastes and a UNDP/GEF assisted project on Development of High Rate Biomethanation Processes as a means of Reducing Green House Gases Emission.

2.1.1. Waste-to-energy

The National Programme on Energy Recovery from Urban and Industrial Wastes was launched during the year 1995–1996 with the following objectives [i] creation of conducive conditions with financial and fiscal regime to promote, develop and demonstrate the utilization of wastes for recovery of energy; [ii] improvement in the waste management practices through adoption of renewable energy technologies for processing and treatment of wastes prior to disposal; and [iii] promotion of projects for recovery of energy from wastes from Urban and Industrial sectors.

The National Bio-Energy Board [NBB], Ministry of Non-Conventional Energy Sources [MNES], Government of India has retained MWH to prepare a National Master Plan [NMP] for development of Waste-to-Energy [WTE] projects in India. The ministry has implemented a UNDP/GEF assisted Biomethanation project. The NMP is an integral part of the UNDP/GEF assisted Biomethanation project and this effort will lead to setting up of several large Waste-to-Energy demonstration projects in various waste streams [19].

The NMP focuses on the cost-effective treatment, stabilization of urban and industrial wastes with optimal bio-energy recovery and efficient energy/power generation form 423 Class I cities and 10 selected industrial sectors. It incorporates a wide array of liquid and solid waste collection, treatment including high rate biomethanation, energy recovery, and disposal. The NMP focuses into utilization technologies that are applicable to the Indian community, conditions, and support ongoing adaptation to meet implementation needs.

The development and implementation of NMP is based on long-term cost benefits and several tangible and intangible benefits including environmental pollution control, socio-economic effects, and reduction in emission of Green House Gases [GHG]. Biomethanation of organic wastes enable India to make its contribution in protecting the global and local environment.

Biomethanation of organic wastes is a very extensively researched subject and the technological basis of optimum generation, purification, and energy recovery is substantially established. Less established are issues related to economics of biogas generation and its optimal end uses. However, these facets of biogas production and utilization have been matters of intensive investigation on a global basis. Overall, information resources related to biogas generation, purification and utilization are extensive and in the main, are transferable geographically. On a national basis, India produces an extremely diverse range of organic waste material, which will in practical terms be available for bio-methanogenic degradation.

Currently, urban and industrial wastes throughout India receives either no treatment or partial treatment before its final disposal, except in few exceptional cases. This practice leads to severe environmental pollution problems including water, ground and air pollution and creates a major threat to human health. There is an absolute need to provide adequate waste collection and treatment before its disposal. A WTE program as envisioned under the NMP, not only provide solution to environmental pollution problems, but also maximizes energy recovery from waste in a cost-effective and proven manner.

This NMP incorporates a wide array of bio-solids collection, treatment including high rate biomethanation, energy recovery and bio-solids disposal and utilization technologies that are applicable to the Indian community, conditions and supports ongoing adaptation to meet implementation needs. The NMP equally emphasizes on the project funding from national and international resources, implementation, operation and maintenance issues.

2.1.2. Major activities of the programme [19]

- Preparation of structured database
- Assessment of current R&D programs
- Identification and analysis of technological options

- Develop and prioritize shelf of projects
- Identify technology transfer mechanisms
- Develop investment strategies
- Study of Government infrastructure
- Develop national master plan

2.1.3. Preparation of structured database

The data related to existing population, solid and liquid waste management systems, solid and liquid waste quantity and quality, future variations, potential of energy recovery, socio-economical issues, existing waste-to-energy projects for all the 423 Class I cities [as per 2001 Census] and 10 industrial sectors has been collected, reviewed, and analyzed.

Data with respect to solid and liquid waste management systems, spatial distribution of units, production capacity of industrial units, solid and liquid waste quantity and quality and potential for energy recovery has been collected for 10 potential industrial sectors namely, pulp and paper, distilleries, dairy, poultry, tanneries, slaughter houses, cattle farm waste, sugar, maize and tapioca starch.

2.1.4. Assessment of current R&D programs

A Technical Memorandum to summarize the work done so far, throughout the world, on waste-to-energy, with particular emphasis on biomethanation has been prepared. Current programmes in various National and International Laboratories, R&D institutions and other agencies have been reviewed and assessed. An extensive literature search has been conducted through various networks to collect the relevant information. The institutes have been contacted for the verification of the database wherever necessary.

2.1.5. Identification and analysis of technological options

All the available technologies for conversion of waste-to-energy for municipal and industrial liquid and solid wastes for different set up of parameters and environmental conditions have been studied. Inventory of all technologies with the influencing and operating parameters is prepared and evaluation of technology is done with respect to Indian conditions.

2.1.6. Develop and prioritize shelf of projects

Based on the database developed, R&D initiatives assessed and waste-to-energy technologies evaluated, a spectrum of viable projects, in terms of clusters of cities and sectors [categories] of industries, is delineated for further prioritization. These clusters of cities and sectors of industries are identified by eliminating the prima facie nonviable options and is essentially based on the homogeneity of the "waste-to-energy potential".

Most viable projects identified are further prioritized using Project Prioritization System [PPS]. Prioritized projects are sorted and listed in different ways including on regional and sector basis for various purposes.

2.1.7. Identify technology transfer mechanisms

In order to ensure implementation of the prioritized most viable projects in a cost-effective manner and to provide a comfort level to the NBB and the owner/operators of the projects, an model for technical collaboration/technology transfer for the priority areas has been developed. The transferability of the technology has been investigated so as to ensure that the suggested technologies can be effectively implemented or taken up by potential entrepreneurs in India.

2.1.8. Develop investment strategies:

National and international funding institutes for funding the viable projects have been identified. The basic funding requirements and the funding strategies have been prepared in conjunction with the financial institutions. Basic checklists are prepared for assisting the NBB in finalizing the financial institutions and the funding mechanism for the shelf of viable projects.

Private funding strategies are developed, giving special emphasis on the methodological operations like, design-built-operate [DBO], design-built-own-operate [DBOO], built-own-operate [BOO] and built-own-lease-transfer [BOLT]. The funding strategies will be evolved taking into account the requirements of the technology, legal and regulatory aspects of the country.

2.1.9. Study of Government infrastructure and suggest changes:

Various policy, legal, regulatory and institutional mechanisms that are in place have been reviewed and the measures to be taken to establish firm linkages between pollution control requirements, waste-to-energy generation, funding, implementation and operation of waste-to-energy projects; as also the role of and interactions among key players like the central and state government, regulatory authorities, local bodies, industries and financial institutions have been identified.

2.2. National master plan

National master Plan on Waste-to-energy has been prepared to serve the basis for the evolution and implementation of a national strategy on Waste-to-Energy sector throughout the country. The NMP has a detailed Strategic Action Plan [SAP] in addition to the summarization of information collected and analyzed under above Main Activities.

2.2.1. Financial incentives

Financial Incentives being provided for eligible waste-to-energy projects under National Programme on Energy Recovery from Urban and Industrial Wastes are given below:

2.2.2. Commercial projects

Interest subsidy is provided for reducing the rate of interest to 7.5% [4% in case of Municipal Solid Waste [MSW] based projects taken up by the Municipal Corporations/Urban Local Bodies]. The amounts of interest subsidy capitalized with an annual discount rate of 12%, given to Financial Institutions [FIs]/Lead FI are as follows [Table 8]:

2.2.3. Demonstration projects

Assistance of up to 50% of capital cost of the project limited to Rs. 3.00 crore per MW for demonstration projects to generate power from Municipal Solid Wastes and a few selected Industrial Wastes.

2.2.4. Power generation at sewage treatment plants [STPs]

Financial assistance of up to 50% of the incremental capital cost for generation of power from biogas.

2.2.5. Urban local bodies

Financial Incentive @ Rs. 15.00 lakh per MWe is payable to Municipal Corporations/Urban Local Bodies, for providing garbage free of cost at the project site and land on long-term [30 years+]

Table 8
Various incentives for commercial projects [19].

SN.	Type of project	Maximum eligible interest subsidy (Rs. in crore/MW)	
		Urban and municipal waste	Industrial waste
1	Waste to power	2.00	1.50
2	Waste to fuel	0.05	0.50
3	Fuel to power	1.00	1.00



Fig. 5. 4800 cum Biogas per day biomethanation plant based on starch industry liquid waste by M/s. Anil products Ltd., Ahmedabad, Gujarat [19].

basis on nominal lease rent. However this incentive will be reduced to 50% in case of projects for generation of power from fuel or fuel from waste.

2.2.6. State nodal agencies

Financial incentives @ Rs. 5.00 lakh per MWe is payable to State Nodal Agencies for promotion, co-ordination and monitoring of projects. However, this incentive will be reduced to 50% in case of projects for generation of power from fuel or fuel from waste.

2.2.7. Financial institutions

A service charge of 2% of the actual subsidy channelized through the FI to the promoter or other FIs, subject to a maximum of Rs. 2.00 lakh per project.

2.3. Preparation of detailed project report [DPR]

50% of the cost of preparation of DPR or Techno-economic Feasibility Reports, subject to a maximum of Rs. 2.00 lakh per report to Urban Local Bodies only.

2.3.1. Financial assistance for resource assessment studies

Financial assistance may also be provided to carry out studies to assess resources for setting up Waste-to-Energy projects.

2.3.2. Financial assistance for promotional activities

Financial assistance can also be provided to organize Training Courses, Business Meets, National Workshops and Seminars, creation of awareness and publicity [Fig. 5].

2.3.3. Implementation arrangements

The National Programme for Energy Recovery from Urban and Industrial Wastes is implemented through the State Nodal Agencies, Govt. Departments, and Urban Local Bodies who have to forward the project proposals to MNES in accordance with a prescribed procedure for applying for Central Financial Assistance. This scheme is applicable to both, private as well as public sector entrepreneurs and investors having technical and managerial capabilities for implementing such projects on the basis of Build Own Operate & Transfer [BOOT], Build Operate & Transfer [BOT], Build Own & Operate [BOO], Build Operate Lease & Transfer [BOLT].

2.4. Other incentives available in the sector [20]

Table 9 is showing various fiscal incentives available for biomass power generation.

Table 10 is showing an overview of state government/utility policies and incentives for energy from waste power generation.

2.4.1. Implementation strategy [19]

The programme would be implemented through nodal departments/agencies of the States/UTs, KVIC, institutions and NGOs. The projects to be taken up by any village level organization, institution, private entrepreneurs etc in rural areas as well as areas covered under the Remote Village Electrification [RVE] programme of MNES other than the industries and commercial establishments covered under Urban, Industrial & Commercial Applications [UICA] programmes for sale of electricity to individual/community/grid etc. on mutually agreeable terms.

Table 9
Fiscal incentives available for biomass power generation.

SN.	Item	Description
1	Income tax	
	Depreciation	100% depreciation in the first year can be claimed for the following power generation equipment
		1 Fluidized bed boilers
		2 Back pressure, pass-out, controlled extraction, extraction and condensing turbine for Power generation with boilers
		3 High efficiency boilers
		4 Waste heat recovery equipment
	Tax holiday	10 year tax holiday
2	Customs duty	Duty leviable for NRSE power projects of less than 50 MW capacity (under Project Import Category) is 20%. This covers machinery and equipment components required for generation of electric power.
3	Central excise duty	Exempted for renewable energy devices, including raw materials, components and assemblies.
4	General sales tax	Exemption is available in certain states.

Table 10
An overview of state government/utility policies and incentives for energy from waste power generation [20].

SN.	Item	Description
1	Power wheeling charges	Nil – 20% of the Energy Exported.
2	Power banking charges	2%
3	Power banking Period	Nil to 12 Months
4	Buy back Rate by SEB/State utility	Rs. 2.75/- to Rs. 3.16/- per unit
5	Third Party sale	
	Capital subsidy by State Government	1 Some states participate as equity in the project 2 Some states provide capital subsidy of Rs. 25 lakh/MW

2.4.2. UNDP/GEF assisted project

The project on "Development of High Rate Biomethanation Processes" is being implemented since 1994. The project envisages setting up of demonstration sub-projects for wastes from seven sectors namely, Sewage, Slaughterhouse, Leather & Tannery, Pulp & Paper, Vegetable market yards, Fruit & Food Processing and Animal manure besides Utilization of biogas for power generation.

The overall developmental objectives of the project are as follows:

- Institution and capacity building;
- Promotion of biomethanation technology through setting up of demonstration sub-projects and organization of seminars and workshops, training, etc.;
- Development of a National Master Plan; and
- Publication of a quarterly newsletter 'Bio-Energy News'.

2.5. Implementation of waste-to-energy projects

2.5.1. Waste-to-energy projects installed/commissioned [19]

[i] Project for generation of 2 MW power from biogas by M/s Saraya Distillary, Gorakhpur, U.P.
[ii] 25 KWe Biomethanation project based on leather solid waste [chrome shavings] at M/s. Tata International Ltd., Dewas
[iii] Project for generation of 0.5 MW power from Tapioca Processing Industry at M/s Varalakshmi Starch Industry Ltd., Salem, Tamil Nadu

2.5.2. Waste-to-energy projects under installation [19]

[i] 5 MW power and 75 tonne per day biofertilizer from Municipal Solid Waste of Lucknow city, on BOO Basis by M/s Asia Bio-energy India Ltd., Chennai. [Fig. 6]
[ii] Project for generation of 1.3 MW power from Poultry droppings by M/s. G.K. Bio-Energy Pvt. Ltd., Namakkal, Tamil Nadu
[iii] Project for generation of 4 MW power from Starch Industry Solid Waste by M/s Vensa Biotek, Samalkot, A.P.
[iv] Project for generation of 3 MW power from Palm Oil Industry Waste by M/s MPR Power Projects Pvt. Ltd., Hyderabad
[v] Project for generation of 1 MW power from animal manure at Ludhiana by Punjab Energy Development Agency, Chandigarh.
[vi] Project for generation of 1.25 MWeq biogas from Bagasse wash effluent at M/s. Tamil Nadu Newsprint and Papers Ltd., Karur, Tamil Nadu
[vii] Project for generation of 0.5 MW power from abattoir wastes by M/s. Hind Agro, Aligarh, U.P.
[viii] Project for generation of 150 kW power from vegetable market waste by Municipal Corporation, Vijayawada, A.P.

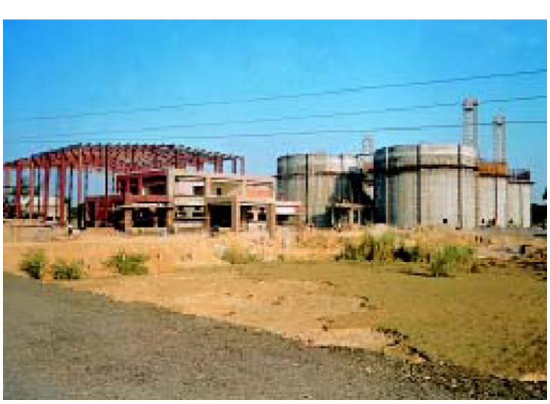


Fig. 6. 5 MW power and 75 tonne per day biofertilizer from municipal solid waste of Lucknow city, by M/s Asia Bio-energy India Ltd., Chennai.

[ix] Project for generation of 0.5 MW power from biogas generated at Sewage Treatment Plant by Surat Municipal Corporation.

2.5.3. Waste-to-energy projects under development [19]

[i] Project for generation of 6.6 MW power from Municipal Solid Waste in Hyderabad city by M/s SELCO International Ltd., Hyderabad
[ii] Project for generation of 5.7 MW power from Municipal Solid Waste in Vijayawada city by M/s Shriram Energy Systems Pvt. Ltd., Hyderabad
[iii] Project for generation of 11 MW power from Municipal Solid Waste in Hyderabad city by M/s RDF Power Projects Ltd., Hyderabad
[iv] Project for generation of 2 MW power from Sugar Cane press mud by M/s St John Sangam Trust, Perambalur, Tamil Nadu
[v] Project for generation of 6 MW power from poultry waste by M/s Kakatiya Alloys Pvt. Ltd., Rangareddy Distt., A.P.
[vi] Project for generation of 2 MW power from Furfural Industry waste by M/s. Delta Agro Chemicals Ltd., Krishna Distt., A.P.
[vii] Project for generation of 3 MW power from Poultry Waste by M/s Ramaprasad Pvt. Ltd., Tanaku, A.P.
[viii] Project for generation of 7.5 MW power from poultry waste by M/s Rajabhaskar Power Pvt Ltd., Mundargi Vill., Billary Dist. Karnataka.
[ix] Project for generation of 3.6 MW power from Poultry waste by M/s Raus Power Pvt. Ltd., Anaparthy Vill., East Godavari Dist. A.P.

2.5.4. Training programmes/conferences

[i] One training programme on Clean Development Mechanism was organized for senior officials in the USA and The Netherlands during May–June 2002 [19].
[ii] Financial support has been provided for the organization of seminars/workshops on 'waste-to-energy' by NGOs, Govt. Departments and consultancy organizations for creating awareness in different parts of the country.

2.5.5. Policy guidelines for waste-to-energy programme [19]

Various State Governments were requested to issue policy guidelines for encouraging the setting up of waste-to-energy projects in their respective States. State Governments of Kerala and Gujarat issued the policy guidelines during the year 2002–2003. Thus the total number of States, which have announced policy measures for waste-to-energy programme, has risen to 10.

3. Municipal solid waste management

Every country, or rather a developing country, should have objectives by which solid waste management is operated. The following are the few suggestions that may be applicable in an urban area.

As we know that municipal solid waste is urban refuse collected for land filling and including paper, organic matter, metals, plastic, etc., but not certain agricultural or industrial wastes. Over the last two decades human activity has begun to play an increasingly significant role in bringing about the changes in the environment, largely due to two developments: the industrial revolution and unprecedented growth in human population.

Today, Haridwar is experiencing the problem due to mounting solid waste, this situation had been brought about by:

1. Better and improving standard of living
2. Growth of consumerism

3. Population growth
4. Increasing presence of substances in the municipal waste stream which are difficult to degrade/breakdown.
5. Increasing industrial activities
6. Poor public participation in finding solutions.
7. Lack of recognition of solid waste as a problem demanding attention and action by the regulatory agencies.

Solid waste from municipal, hospital and industries is a problem that needs serious attention. The issues involved are diverse. For some wastes the non availability of space for disposal is the main problem. For other waste the problem is one of the improper disposals. The effect of the later may range from simple aesthetic consequences to one of safety and health issues involving human/biological and ecological risk. The magnitude of the problem in present is not huge, though the deteriorating situation is all too common to observe. Thus argent attention needs to be given to this problem in Haridwar city [India].

3.1. Objective of the project

The objective of the study is to analyze the MSW of Haridwar city chemically and suggest a energy conversion technology for managing that waste and to generate power from the waste in an efficient way and to prepare a feasibility report for power generation from the MSW of Haridwar city.

3.1.1. Amount of waste generated

The city generates, on an average, about 190MT of MSW per day. The major sources of MSW generation of the city are domestic, shops and commercial establishments, hotels, restaurants, dharamsalas and fruit and vegetable markets. Number of registered hotels, restaurants and dharamsalas in the city are 270, 250 and 280 respectively. In addition there are 3 fruit and vegetable markets. Quantity of waste generated from various sources are presented in Table 11 [21].

Table 11
Solid waste generated from different sources (Tonne/day) [21].

SN.	Source	Generation
1	Domestic	155
2	Fruit and vegetable markets	5
3	Shop and commercial establishments	12
4	Hotel, restaurants and dharamsalas	4
5	Construction/demolition activities	2
6	Other	12
Total		190

Table 12
Vehicle presently being utilized by HNNP for transportation of MSW.

SN.	Type of vehicle	Total quanity (No.)
1	Tractor trolley	6
2	Container carrier tractor	3
3	Tipper truck	5
4	Mechanical loader	2
5	Dumper placer	2
6	Refuse compactor	1
7	Vikram three wheeler	6

3.1.2. Collection storage and transportation

There is practically no primary collection system in the city except in few localities where the Mohalla Swachhata Samities [MSS] recently have started door to door primary collection by engaging private sweepers. Waste is mostly collected through community bins/containers and road sweeping. HNPP sweepers and sanitary workers engaged by the MSS sweep the streets. They accumulated the collected waste into small heaps and subsequently loaded manually or mechanically onto the community containers/bins or directly loaded onto the solid waste transportation vehicles for onward transportation to the disposal site. Haridwar Nagar Palika Parishad [HNPP] presently utilizes the following vehicles and equipment for transportation of solid waste [Table 12].



Fig. 7. Map of Haridwar district showing MSW dumping site of Haridwar city [22].

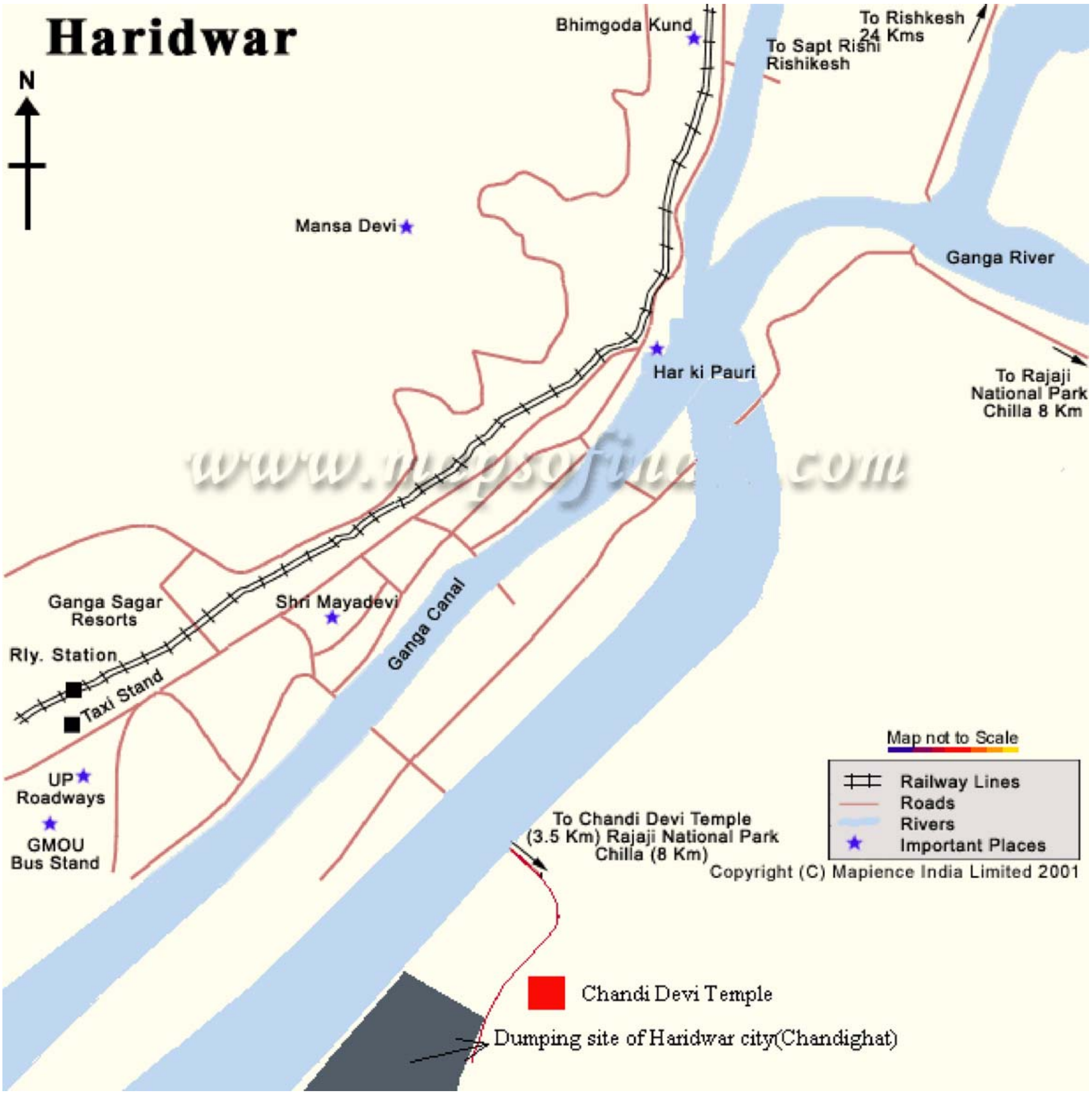


Fig. 8. MSW dumping site at Haridwar [Chandighat] [22].

3.1.3. Dumping sites of Haridwar

At present HNPP disposes the solid waste of the city to one site located at the side of the national highway-74 at a distance of about 8 km from the city. In this site waste disposal is done by uncontrolled dumping. HNPP owns about 14.50 ha of land at sarai village, located at a distance of about 12 km from the city for future solid waste disposal.

3.2. Details of dumping site

Name of dumping site: Chandighat [Fig. 7].



Fig. 9. Dumping site of Haridwar city at Chandighat.



Fig. 10. Municipal vehicles dumping MSW to the dumping site at Haridwar [Chandighat].

Location: beyond the bridge of Chandighat, 2.5 km from bus stand of Haridwar city.

Distance from municipal council of Haridwar city: 5 km.

Area of dumping site: 1.5 km^2.

As it can be clear from the Figs. 7 and 8 MSW dumping site at Haridwar city which is Chandighat. This picture is taken from the http://www.indiamaps.com.

Figs. 9 and 10 showing a view of dumping site of Haridwar city where a municipality vehicle is dumping the MSW.

3.3. Detailed analysis of MSW of Haridwar

3.3.1. Sampling

To determine the physical and chemical characteristics of MSW there were total 12 samples collected from the different points of the dumping site as indicated in Fig. 11 Out of these 3 samples were collected from the recently unloaded truck. The depth of collection points from the earth level is 1 feet.

The sample size of each sample was 1 kg. Samples were weighed on a complete sample basis and on an each individual component basis. These samples are then subjected to natural drying in sunshade for the period until the moisture is removed completely. The moisture free samples were again weighed and weight of each component was determined on dry basis. This gave the percentage amount of moisture in the MSW.

3.3.1.1. Composition of MSW on as received basis and on dry basis.. Table 13 shows the composition of MSW of Haridwar city on as received basis and on dry basis. With the help of the table it is calculated that the average amount of biodegradable and non-biodegradable material is around 58% and 28% respectively and the average amount of moisture is around 14%.

Where,

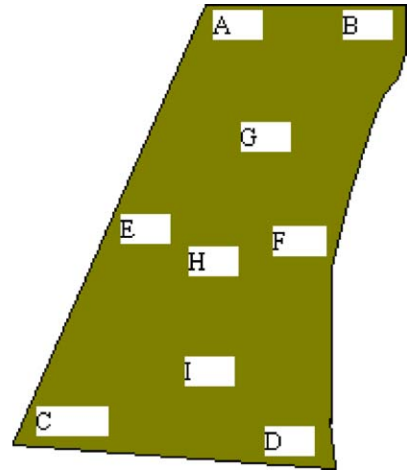


Fig. 11. Representation of sample collection scheme.

YW: yard waste
VEG: vegetable waste
PW: paper waste
CL: clothes
AR: as received basis
GL: glass
PL: plastic
TH: thermacoal
SL: silt/boulders/clay
DB: dry basis

3.3.2. Energy contents

Then after sorting the samples are converted into powder and then by the use of brequetting machine the powdered sample is converted into briquettes.

The calorific value is determined for both the basis [as received basis and dry basis] using bomb calorimeter.

Table 13
Composition of MSW of Haridwar city.

S.N	Composition		Biodegradable				Non-biodegradable					Total (%)	Moisture content (%)
	Sample		YW	VEG	PW	CL	GL	PL	TH	SL	CL		
1	A	AR	25.2	28.5	9.2	1.15	1.6	6.5	.6	26	1.2	100	
		DB	21.5	23.6	8	1	1.6	6.5	.4	20	1	83.6	16.4
2	B	AR	30.2	12.6	14.5		2.6	4.8	1.8	33.5		100	
		DB	27.5	9.2	13.2		2.6	4.8	1.5	28		86.8	13.2
3	C	AR	28.6	29.5	10.2	1.7	.2	7.8		22		100	
		DB	25.2	24.8	8.7	.15	.2	7.8		17.5		85.7	14.3
4	D	AR	21.5	28.2	8.5	.6	.5	5.8		34	.9	100	
		DB	18.6	26.2	6.8	.5	.5	5.8		29.5	.8	88.7	11.3
5	E	AR	30.4	24.2	7.8	1.1		1.1		35.4		100	
		DB	28	22.8	5.9	.9		1.1		30.5		89.2	10.8
6	F	AR	31.5	12.8	9.2		.8	2.8		42.9		100	
		DB	29.2	10.2	6.3		.8	2.8		38		87.3	12.7
7	G	AR	17.5	28.6	9.8	1.8			.8	41.1	.4	100	
		DB	15.8	25.5	6.7	1.6			.6	37.2	.3	87.8	12.2
8	H	AR	24.5	30.2	4.8	.7		4		35	.8	100	
		DB	20.4	17.8	2.9	.6		4		30.2	.6	76.5	23.5
9	I	AR	20.5	17.8	4.2		2.7	1.7		53.1		100	
		DB	18.5	15.2	3.1		2.7	1.7		47.2		88.4	11.6
10	J	AR	31.7	14.8	4.7		.2		1.4	47.2		100	
		DB	19.2	12.3	3.8		.2		1.1	40.8		77.4	22.6
11	K	AR	31.8	12.5	8.2	1.1		1		42.4	3	100	
		DB	30.2	9.8	6.9	.95		1		37.5	2.55	88.9	11.1
12	L	AR	34.5	21.5	9.7	1	.9	4.8		27.6		100	
		DB	32.4	18.3	7.4	.8	.9	4.8		24		88.6	11.4

Table 14
Energy contents of MSW samples (as received basis and dry basis).

SN	Sample	Calorific value of biodegradable material in MSW only (KJ/kg)	Calorific value of whole MSW (KJ/kg)
1.	A	17,770	10,726
2.	B	17,130	7524
3.	C	13,928	6403
4.	D	14,888	8805
5.	E	17,290	8805
6.	F	14,568	8645
7.	G	17,130	8645
8.	H	13,447	8164
9.	I	16,169	8965
10.	J	16,809	8004
11.	K	16,809	7204
12.	L	16,649	6723
	Average	16,049	8217

Table 14 shows the energy contents of MSW samples. As it is shown the calorific value of biodegradable matter of the waste is around 16048 KJ/kg while calorific value of MSW as received basis is around 8217 KJ/kg.

3.4. Proximate analysis of MSW sample

To know the volatile matter [VM], fixed carbon [FC], moisture content and ash content proximate analysis is carried out using ASTM standard method.

3.4.1. Result of proximate analysis [as received basis]

Table 15 indicates the results of proximate analysis MSW on received basis. The average value of fixed carbon and volatile matter is 17% and 21% respectively.

Fig. 12 shows the standard energy triangle according to which for Indian MSW the best energy conversion technology is biomethanation process. According to triangle biomethanation process is the best energy conversion technology if the MSW contains the following characteristics.

Moisture contents 5–52%
Volatile matter 8–35%
Non-combustibles 24–84%
As it is clear from the results of the proximate analysis:
Moisture contents 21%
Volatile matter 21%
Non-combustibles 58%

Therefore the best energy conversion technology is biomethanation for the MSW of Haridwar city.

Table 15
Result of proximate analysis (as received basis).

SN.	Sample	Moisture (%)	VM (%)	Ash (%)	FC (%)
1	A	19.4	17.1	39.5	24
2	B	18.2	15.9	45.9	20
3	C	22.3	31.2	28.5	18
4	D	18.3	26.1	38.6	17
5	E	14.8	24.6	37.6	23
6	F	21.7	20.5	42.8	15
7	G	16.2	15.7	48.1	20
8	H	32.5	16.7	36.8	14
9	I	18.6	18.5	50.9	12
10	J	28.6	7.5	48.9	15
11	K	18.1	18.9	46	17
12	L	18.4	36.8	31.8	13
Average		20.5	21	41.2	17.3

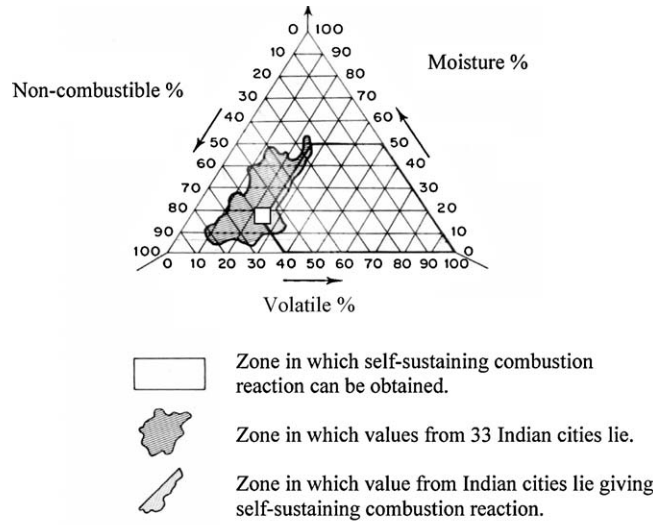


Fig. 12. Energy triangle or three component diagram illustrating suitability of Indian MSW for biomethanation process [23].

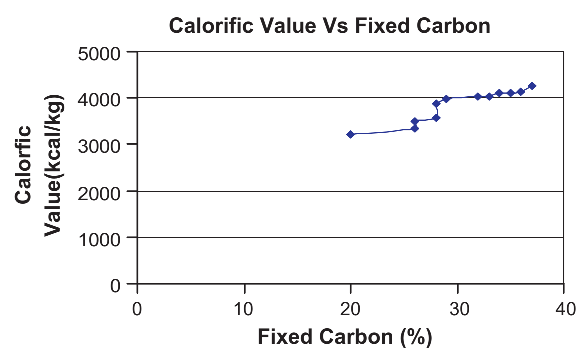


Fig. 13. Relationship between calorific value and fixed carbon.

3.4.2. Important relationships

Depending upon the result of proximate analysis of Haridwar MSW the following relationships has been developed:

3.4.2.1. Relationship between calorific value and fixed carbon. It is mentioned in Fig. 13 that as the percentage of fixed carbon increases the calorific value also increases. Figure shows the trend of variation of calorific value with fixed carbon.

3.4.2.2. Relationship of calorific value vs. moisture content. It is shown in Fig. 14 as the % of moisture content increases the calorific

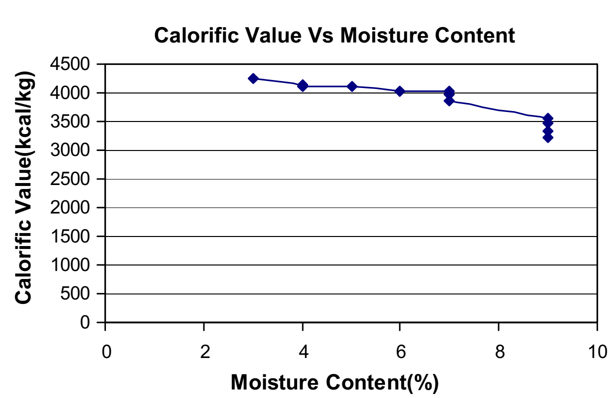


Fig. 14. Relationship between calorific value and moisture content.

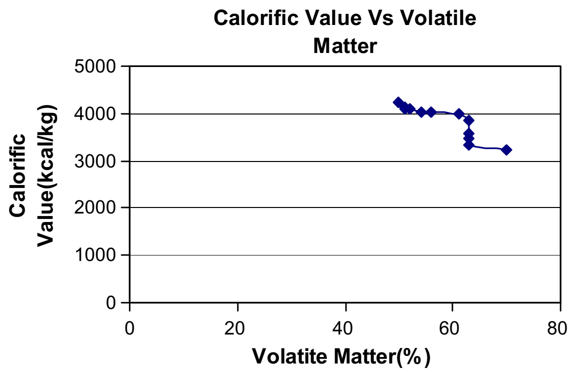


Fig. 15. Relationship between calorific value and volatile matter.

value of the sample decreases. Figure shows the trend of variation of calorific value with moisture content.

3.4.2.3. Relationship of calorific value vs. volatile matter. Fig. 15 indicates, as the % of volatile matter increases the value of calorific value decreases. Figure shows the trend of variation of calorific value with volatile matter.

3.5. TGA/DTA analysis

Thermal analysis comprises a group of techniques in which a physical property of a substance is measured as a function of temperature, while the substance is subjected to a controlled temperature programme.

3.5.1. TGA analysis

Thermo gravimetric Analysis or TGA is a type of testing that is performed on samples to determine changes in weight in relation to change in temperature. Such analysis relies on a high degree of precision in three measurements: weight, temperature, and temperature change. As many weight loss curves look similar, the weight loss curve may require transformation before results may be interpreted. A derivative weight loss curve can be used to tell the point at which weight loss is most apparent.

3.5.2. DTA analysis

In differential thermal analysis, the temperature difference that develops between a sample and an inert reference material is measured, when both are subjected to identical heat treatments. DTA involves heating or cooling a test sample and an inert reference under identical conditions, while recording any temperature difference between the sample and reference. This differential temperature is then plotted against time, or against temperature. Changes in the sample which lead to the absorption or evolution of heat can be detected relative to the inert reference.

To know the changes in physical properties of MSW samples with change in temperature a TGA/DTA analysis on MSW samples has been carried out in Institute Instrumentation Center.

Model description
Model name: Pyres Diamond TGA/DTA analyzer
Company name: Perkin Elmer
Following are the conditions, selected for the test
Maximum temperature of test = 1200 °C
Rate of heating = 100 °C/min.
Medium of test = air

The results of TGA/DTA analysis are reported in Table 16.

Table 16 shows the result of TGA/DTA analysis in terms of rate of mass loss and % mass left with temperature. The rate of mass loss is maximum in the range of 300–500 °C. After that rate of mass loss is decreasing sharply and beyond 800 °C it is near zero.

Table 17 indicates the % weight loss with temperature. It can be seen that the average weight loss between 100 and 300 °C is 24.6%, between 300 and 500 °C is 43.84%, between 500 and 800 °C is 15.9%

Table 17
Showing percentage weight loss with temperature.

SN.	Sample	Weight loss (%)with temperature			
		100–300 °C	300–500 °C	500–800 °C	800–1200 °C
1	A	18	30.2	13.9	0.6
2	B	25.6	34	13.9	1.0
3	C	32.9	40.9	16.3	2.64
4	D	27	47	12.4	2.3
5	E	36.5	38.8	18.1	2.32
6	F	18.9	56.4	9.9	2.04
7	G	19.6	48.6	16.2	1.66
8	H	28.6	49.5	10.15	1.65
9	I	24.21	46.55	18.84	2.24
10	J	27.96	40.87	16.21	0.72
11	K	18.18	46.24	19.48	1.31
12	L	18	47	25.4	1.4
Average		24.6	43.84	15.9	1.65

Table 16
Result of TGA/DTA analysis.

SN	T (°C)	Sample physical property	A	B	C	D	E	F	G	H	I	J	K	L
1	100	Rate of mass loss (mg/min)	0.61	0.6	0.65	0.5	0.5	0.68	0.7	0.8	0.7	0.7	0.88	0.7
		Mass left (%)	95.7	96.5	96.9	95	98	95.9	95.4	95.6	95	95	93.7	95
2	200	Rate of mass loss (mg/min)	0.60	0.6	0.8	0.5	0.5	0.6	0.6	0.78	0.6	0.6	0.8	0.7
		Mass left (%)	91.8	91.7	89	89	90.4	88.6	89	88.2	89.2	89.8	87.5	90
3	300	Rate of mass loss (mg/min)	5.0	8.0	7.5	8	8.0	7.8	6.2	12.4	6.2	7.4	8	7.5
		Mass left (%)	77.7	70.9	64	68	61.5	77	75.8	67	70.9	67.1	75.5	77
4	400	Rate of mass loss (mg/min)	1.70	1.8	2	2.5	2.6	2.6	4.8	0.8	1.8	2.0	2.2	2.6
		Mass left (%)	54.5	45	34	32	34.8	36	40	28	35	39.1	45.6	34
5	500	Rate of mass loss (mg/min)	1.70	1.7	1.6	1.4	0.63	0.72	0.84	0.78	1.2	1.4	0.75	0.9
		Mass left (%)	47.5	36.9	23.1	21	22.7	20.6	27.2	17.5	24.2	26.2	29.3	30
6	800	Rate of mass loss (mg/min)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Mass left (%)	35	23	6.8	8.6	4.6	10.7	11	7.35	5.4	10	9.78	4.6
7	1000	Rate of mass loss (mg/min)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Mass left (%)	34.6	22	5	6.8	2.0	9.06	10	6.09	3.62	9.58	8.58	7.2
8	1200	Rate of mass loss (mg/min)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Mass left (%)	34.4	22	4.16	6.3	2.28	8.66	9.34	5.7	3.16	9.28	8.47	6.2

Table 18
Total energy content of biogas produced from MSW of Haridwar city.

SN.	Heating value of biogas (MJ/m^3)	Biogas generated per day (m^3)	Energy value of biogas (MJ/day)
1	20	140	532,000

and between 800 and 1200 °C is 1.65%.it is clear from the Table 17, the major part of mass is lost between 300 and 500 °C. Therefore the MSW samples are not suitable for combustion at high temperature. As the temperature of direct incineration process is around 1200 °C, the MSW of Haridwar city is not suitable for incineration process but for biological process it is suitable.

4. Potential of MSW for Haridwar city

As per the chemical composition of the MSW of Haridwar city the bio gas generated per tonne of MSW = 140 m^3

The energy value of that	=20 MJ/m^3
So total biogas generated per day	=190 × 110 m^3
	=26,600 m3
Energy content of biogas	=532,000 MJ/day

The data is given by SKG Sangha, a leading manufacturing company of biogas plant of India. Table 18 is showing the total energy content of biogas produced from MSW of Haridwar city.

5. Biogas plant

5.1. Salient features of biogas plant [24–26]

- The HRT of the plants will be 10–15 days for 2 different kinds of materials. We have to pulverize and chop and mix the feed materials. We can produce between 25,000 and 30,000 m^3 of biogas per day with the available materials.
- The slurry comes out of the biogas plant will be dewatered. Water will be used in the biogas generation process and the solid material can be used for fertilizer production.
- Generated gas can be used for power generation or supplied to the houses as domestic fuel after cleaning.

5.1.1. Chemical process

The series of complex reactions involved in the digestion of organic wastes to biogas can be broadly divided into two main phases:

- an acidogenic phase in which the organic wastes are converted mainly to acetate and
- the methanogenic phase in which methane and carbon dioxide are formed.

5.1.1.1. Acidogenic phase. Acid phase fermentation is a key step in biogas production, since it results in the generation of acetate which is the primary substrate for methane formation. The terminal end-products of acid phase fermentation are acetate, higher fatty acids, CO_2 and H_2. The fermentation of these products is mediated by the complicated network of enzymatic reaction chains. The polymeric carbohydrates contained in the complex organic wastes are hydrolyzed by enzymes to simple soluble sugars and short-chain organic acids like acetic acid, propionic acid, lactic acid, etc., and methanol, ethanol, propanol etc.

The primary breakdown of sugar in fermentation is to pyruvic acid, with liberation of hydrogen in the for of a hydrogen-carrier complex. This hydrogen could then be used to reduce pyruvic acid to propionic acid pyruvic acid can also be reduced to ethanol by a different pathway:

$$C_3H_4O_3 + 2H \rightarrow C_2H_6O + CO_2$$

or to lactic acid

$$C_3H_4O_3 + 2H \rightarrow C_3H_6O_3$$

pyruvic acid can also be converted to butyric acid:

$$C_3H_4O_3 \rightarrow C_4H_8O_2 + 2CO_2$$

or converted to succinic acid

$$C_3H_4O_3 + CO_2 + 2H \rightarrow C_4H_6O_4 + H_2O$$

The production of acetic acid from pyruvic acid is:

$$C_3H_4O_3 + H_2O \rightarrow C_2H_4O_2 + H_2 + CO_2$$

The hydrogen can then be used by the methanogenic bacteria to form methane and water:

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

5.1.2. Methane phase

This involves the conversion of the intermediatry products of the acid phase to form methane. The main substrates for methanogenesis are acetic acid and hydrogen plus carbon dioxide. Acetic acid is usually regarded as the most important substrate.

The overall reactions occurring in the second phase of unaerobic fermentation are known; but complete details of the biochemical mechanisms involved are yet to be brought to light. The overall reactions involved in the production of methane can be due to the cleavage and reduction respectively of acetic acid and hydrogen. The cleavage of acetic acid results in the conversion of methyl carbon to methane and carbon dioxide. Carbon dioxide is further reduced to methane.

$$2C_2H_4O_2 \rightarrow 2CH_4 + 2CO_2$$

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$

If the methanogenic bacteria are growing with the sugar-fermentating bacteria the removal of hydrogen will induce the bacteria to form more hydrogen, thus instead of a mixture of acetic and propionic acids:

$$C_6H_{12}O_6 \rightarrow C_2H_4O_2 + C_3H_6O_2 + CO_2 + 4H_2$$

Acetic acid would be produced:

$$C_6H_{12}O_6 + 2H_2 \rightarrow 2C_2H_4O_2 + 2CO_2 + 4H_2$$

The hydrogen formed in the initial split of glucose to pyruvic acid would be released as hydrogen gas and more hydrogen would be released in the formation of acetic acid. The $4H_2$ would be combined with CO_2 to form methane. In a similar way the production of ethanol, lactic acid and the other reactions shown above, would be displaced in favour of acetic acid and hydrogen production.

In the formation of methane from carbohydrate 66% of the methane is estimated to have come from acetic acid while 33% is from hydrogen.

Fig. 16 showing the different application for which MSW can be used.

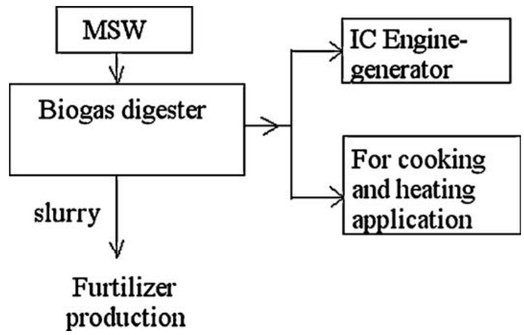


Fig. 16. Different uses of biogas.

5.2. Biogas engines

Biogas can be used as motive power for a variety of agro-industrial and other applications like water pumping, chaff cutting, threshing, washing, small-scale electricity generation, in flour mills, milk chilling units, etc. biogas is being used either as the principle [85–90% of biogas] or as secondary fuel I most of the above operations. Use of biogas in engines necessitates minor to major engine modifications. Today the technologies are available in which it is possible to use biogas in IC engine purely.

5.2.1. Use of biogas in compression ignition engines

Existing CI engines require a minimum of 10–15% of diesel oil injected in the conventional manner for initiation and completion of combustion of biogas air mixture inducted during the suction stroke. The performance characteristics of the engine having dual fuel operation with biogas as the principal fuel [85–90% biogas] and diesel introduced as the secondary fuel, are around to be similar to that obtained when the engine was operated with only diesel as the fuel. There is a reduction in the smoke number and nitric oxide for a higher percentage of biogas substitution; where as the exhaust gas temperature and unburnt hydrocarbon content increase with the increase in biogas substitution. Heating of intake air could increase could increase the rate of combustion which might improve the combustion process, thereby increasing the thermal efficiency of the engine. Similarly biogas gives a better performance if the engine compression ratio is increased. This however involves major engine modifications.

5.2.2. Further it is proposed:

- Paper and clothes waste can be made into pulp and will be used for production of paper and other products.
- Glass can be sold in the market
- Plastic can be recycled
- Thermo-coal also can be recycled
- Silt will be sent to the construction sites for raising the land height.

5.3. Cost analysis for using biogas in CI engine

Biogas can be used in IC engine in two ways as discussed above.

(i) Biogas in IC engine in dual mode with diesel [85% biogas and 15% diesel].
(ii) Biogas in IC engine in pure mode [100% biogas].

Here cost analysis is done for both the cases.

5.3.1. When biogas is used in dual mode with diesel

Biogas = 85%
And diesel = 15%.
Biogas consumed by engine = 26,600 m^3/day
Calorific value of biogas = 20 MJ/m^3
To generate 1 kWh biogas required [as a rule of thumb] =0.6 m^3 [85%]
[With engine efficiency 28% and generator efficiency 93%]
Diesel required to generate 1 kWh = 0.05 L [15%]
Total kWh produced = 26,600/0.6 = 44,333 kWh/day
kWh produced in one year = 13,300,000
[Considering plant is working 300 days a year]
Diesel required per year for the same = 664,995 L
Energy produced = 13,300,000 kWh per year = 1847 kWh/h = 1847 kW = 1.8 MW
Therefore according to above calculation plant capacity = 1.8 MW
Life of power plant, n = 15 years
Interest rate, r = 14%
Cost per unit without subsidy = [total annual cost]/total kWh = [40,000,000]/[1.8 × 1000 × 300 × 24] = Rs. 3.0/-

Table 19 representing the cost analysis of IC engine plant without subsidy when it is running in dual mode.

Table 20 representing the cost analysis of IC engine plant with subsidy when plant is running in dual mode.

5.3.1.1. CDM analysis in case when biogas is used in dual mode with diesel.

GHG emission reduction by the project, leakage [27–29]

1. Emission reduction by the project

Reduction are calculated by using the following formula

Table 19
Cost analysis of IC engine plant in dual mode without subsidy.

SN.	Item		Cost (Rs.)
1	Capital cost	Cost of biogas digester	2,50,00,000
		Cost of diesel engine and generator assembly including installation cost	2,50,00,000
		Cost of waste land	0
		Cost of construction	1,00,00,000
	Total capital cost		6,00,00,000
2	Annual charges	O&M cost (2%)	12,00,000
		Installment of loan	60,00,000
		The interest on investment (14%)	84,00,000
		Depreciation on gas holder and digester assembly (10%)	25,00,000
		Depreciation on engine (10%)	25,00,000
		Cost of running (diesel cost)	2,19,00,000
3	Total annual charges		4,00,00,000
4	Cost per kWh without subsidy without CDM		3.0

Table 20
Cost analysis of IC engine plant in dual mode with subsidy.

SN.	Item		Cost (Rs.)
1	Capital cost	Cost of biogas digester	2,50,00,000
		Cost of diesel engine and generator assembly including installation cost	2,50,00,000
		Cost of waste land	0
		Cost of construction	1,00,00,000
	Total capital cost		6,00,00,000
2	Subsidy		3,60,00,000
3	Annual charges	O&M cost (2%)	12,00,000
		Installment of loan	24,00,000
		The interest on investment (14%)	33,60,000
		Depreciation on gas holder and digester assembly (10%)	25,00,000
		Depreciation on engine (10%)	25,00,000
		Cost of running (diesel cost)	2,19,00,000
4	Total annual charges		3,38,60,000
5	Cost per kWh with subsidy		2.6

Emission reduction by the project = base line emission [**A**] − project emission [**B**]

[A] Base line emission

Base line emission = base line emission from avoided MSW disposal [a] + base line emission from grid-connected power plants [b]

[a] Base line emission from avoided MSW disposal

$= xyijk[16/12]Le^{-k[y-t]}[1-O]G$

Where, x = methane generation rate = 0.05[IPCC default value]

y = degradable carbon fraction in the MSW [%] = 0.18[for India]

i = fraction of DOC that actually degrades [%] = 0.88

j = methane correction factor for land fill = 0.4

k = fraction of methane in the project landfill gas = 0.5[IPCC default value]

L = MSW generated per day in tonne = 190 × [1 − 0.1426] × 365

O = oxidization factor = 0

G = global warming potential of CH_4 = 21

t = year during the crediting period

y = year for which methane emissions are calculated

Base line emission from avoided MSW disposal in first year = 0.05 × 0.18 × 0.88 × 0.4 × 0.5 × [16/12] × 190[1 − 0.1426] × 365 × e^0 × [1 − 0] × 21 = 2783.71 tonne

[b] Base line emission from grid-connected power plants

Base line emission of grid electricity = electricity supplied to the grid × OM

Where, OM = emission factor for conventional sources for the northern region = 0.71 per MWh

Annual generation = 1.8 × 300 × 24 MWh = 12,960 MWh

Base line emission of grid electricity = 12960 × 0.71 = 9201.6 tonne

Base line emission [A] = [a] + [b] = 2783.71 + 9201.6 = 11985.31 tonne

[B] Project emission

Project emission = project emission from burning of fossil fuel origin product in the project plant [c] + project emission from fossil fuel consumption for the project[d]

[c] Emission from the burning of biogas for power generation [28]

Combustion equation of biogas or land filling gas

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

1 mol	1 mol
16 molecular weight	44 molecular weight
1 kg CH_4	2.75 kg CO_2

In biogas according to the Haridwar city MSW characteristics 44.5% is CO_2 and 55.5% is CH_4.

Density of CO_2 = 1.96 kg/m^3

Density of CH_4 = 0.714 kg/m^3

According to the given data 1 m^3 of biogas contains 0.396 kg of CH_4 and 0.87 kg of CO_2.

0.396 kg of CH_4 generates 1.08 kg CO_2.

Therefore total amount of CO_2 generate by burning of 1 m^3 of biogas = 1.08 kg

Now, total amount of biogas generates = 26,600 m^3 per day = 7980000 m^3 per year

Total emission from the burning of biogas for power generation = 7980000 × 1.08 = 8,618,400 kg per year = 8618 tonne per year

[d] Emission for fossil fuel consumption for the project

Amount of diesel used per year = 664,995 L

Per MWh CO_2 emission = 0.0024 [calculated from CEA standard value]

By taking a value of those emission equals to that of emission by diesel, i.e., 31 tonne per year.

Now, the total project emission [B] = emission from the burning of biogas for power generation [c] + emission for fossil fuel consumption for the project [d] = 8618 + 31 = 8649 tonne per year

Emission reduction by the project = base line emission [A] − project emission [B] = 11985 − 8649 = 3336 tonne per year

As according to IPCC norms 1 tonne of CO_2 is equivalent to 7.5 USD.

Now by taking rupee equivalent of 1 USD = Rs. 42/-

Therefore 1 tonne of CO_2 is equivalent to Rs. 315/-

Then 3336 tonne of CO_2 will be equivalent to Rs. 1,050,840/-

Cost per unit [considering carbon credits] = [total annual cost − value of carbon credits]/total kWh = [3,38,60,000 − 1,050,840]/[1.8 × 1000 × 300 × 24] = Rs. 2.5/-

5.3.2. When biogas is used in pure mode [100%]

By considering the case of using biogas 100%

Biogas consumed by engine = 26600 m^3/day

Calorific value of biogas = 20 MJ/m^3

To generate 1 kWh biogas required [as a rule of thumb] = 0.72 m^3

[With engine efficiency 28% and generator efficiency 93%]

Total kWh produced = 26,600/0.72 = 36,944 kWh/day

kWh produced in one year = 11,083,333

[Considering plant is working 300 days a year]

Energy produced = 11,083,333 kWh per year = 1540 kWh/h = 1540 KW = 1.5 MW

Table 21
Cost analysis of IC engine plant in pure biogas mode without subsidy.

SN.	Item		Cost (Rs.)
1	Capital cost	Cost of biogas digester	2,50,00,000
		Cost of diesel engine and generator assembly including installation cost	2,30,00,000
		Cost of waste land	0
		Cost of construction	1,00,00,000
	Total capital cost		5,80,00,000
2	Annual charges	O&M cost (2%)	11,60,000
		Installment of loan	58,00,000
		The interest on investment (14%)	81,20,000
		Depreciation on gas holder and digester assembly (10%)	25,00,000
		Depreciation on engine (10%)	23,00,000
3	Total annual charges		19,880,000
4	Cost per kWh without subsidy without CDM		1.84

Table 22
Cost analysis of IC engine plant in pure biogas mode with subsidy.

SN.	Item		Cost (Rs.)
1	Capital cost	Cost of biogas digester	2,50,00,000
		Cost of diesel engine and generator assembly including installation cost	2,30,00,000
		Cost of waste land	0
		Cost of construction	1,00,00,000
	Total capital cost		5,80,00,000
2	Subsidy		3,00,00,000
3	Annual charges	O&M cost (2%)	11,60,000
		Installment of loan	28,00,000
		The interest on investment (14%)	39,20,000
		Depreciation on gas holder and digester assembly (10%)	25,00,000
		Depreciation on engine (10%)	23,00,000
4	Total annual charges		1,26,80,000
5	Cost per kWh with subsidy		1.20

Therefore according to above calculation plant capacity = 1.5 MW

For the project considering 7 engines of 20 KW and 1 engine of 100 KW

Company name **NATH MOTORS**

Engine specification:

Life of power plant, n = 15 years

Interest rate, r = 14%

Cost per unit with subsidy = [Total annual charges]/total kWh

Table 21 representing the cost analysis of IC engine plant when running in pure biogas mode without subsidy.

Table 22 representing the cost analysis of IC engine plant when running in pure biogas mode with subsidy.

5.3.2.1. CDM analysis in case when biogas is used in pure mode [100%]. GHG emission reduction by the project, leakage [27]

1. Emission reduction by the project

Reduction are calculated by using the following formula

Emission reduction by the project = base line emission [A] − project emission **[B]**

[A] Base line emission

Base line emission = base line emission from avoided MSW disposal [a] + base line emission from grid-connected power plants [b]

[a] Base line emission from avoided MSW disposal

$= xyijk[16/12]Le^{-k[y-t]}[1-O]G$

Where, x = methane generation rate = 0.05[IPCC default value]

y = degradable carbon fraction in the MSW [%] = 0.18[for India]

i = fraction of DOC that actually degrades [%] = 0.88

j = methane correction factor for land fill = 0.4

k = fraction of methane in the project landfill gas = 0.5[IPCC default value]

L = MSW generated per day in tonne = $190 \times [1-0.1426] \times 365$

O = oxidization factor = 0

G = global warming potential of CH_4 = 21

t = year during the crediting period

y = year for which methane emissions are calculated

Base line emission from avoided MSW disposal in first year = $0.05 \times 0.18 \times 0.88 \times 0.4 \times 0.5 \times [16/12] \times 190[1-0.1426] \times 365 \times e^0 \times [1-0] \times 21$ = 2783.71 tonne

[b] Base line emission from grid-connected power plants

Base line emission of grid electricity = electricity supplied to the grid × OM

Where, OM = emission factor for conventional sources for the northern region = 0.71 per MWh

Annual generation = $1.8 \times 300 \times 24$ MWh = 12,960 MWh

Base line emission of grid electricity = 12960×0.71 = 9201.6 tonne

Base line emission [A] = [a] + [b] = 2783.71 + 9201.6 = 11985.31 tonne

[B] Project emission

Project emission = project emission from burning of fossil fuel origin product in the project plant [c] + project emission from fossil fuel consumption for the project [d]

[c] Emission from the burning of biogas for power generation [28]

Combustion equation of biogas or land filling gas

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Table 23
Comparison of two technologies.

SN.	Technology	Installed capacity of plant (MW)	Cost of unit generation (Rs.)
1	85% biogas and 15% diesel in diesel engine	1.8	2.5
2	100% biogas in diesel engine	1.5	1.1

1 mol	1 mol
16 molecular weight	44 molecular weight
1 kg CH_4	2.75 kg CO_2

In biogas according to the Haridwar city MSW characteristics 44.5% is CO_2 and 55.5% is CH_4.

Density of CO_2 = 1.96 kg/m^3

Density of CH_4 = 0.714 kg/m^3

According to the given data 1 m^3 of biogas contains 0.396 kg of CH_4 and 0.87 kg of CO_2.

0.396 kg of CH_4 generates 1.08 kg CO_2.

Therefore total amount of CO_2 generate by burning of 1 m^3 of biogas = 1.08 kg

Now, total amount of biogas generates = 26,600 m^3 per day = 7,980,000 m^3 per year

Total emission from the burning of biogas for power generation = 7,980,000 × 1.08 = 8,618,400 kg per year = 8618 - tonne per year

[d] Emission for fossil fuel consumption for the project

Amount of diesel used per year = 6000 L

Per MWh CO_2 emission = 0.0024[calculated from CEA standard value]

By taking a value of those emission equals to that of emission by diesel, i.e., 14 tonne per year.

Now, the total project emission [B] = emission from the burning of biogas for power generation [c] + emission for fossil fuel consumption for the project [d] = 8618 + 14 = 8632 tonne per year

Emission reduction by the project = base line emission [A] − project emission [B] = 11,985 − 8632 = 3353 tonne per year

As according to IPCC norms 1 tonne of CO_2 is equivalent to 7.5 USD.

Now by taking rupee equivalent of 1 USD = Rs. 42/-

Therefore 1 tonne of CO_2 is equivalent to Rs. 315/-

Then 3336 tonne of CO_2 will be equivalent to Rs. 1,056,195/-

Cost per unit [considering carbon credits] = [total annual charges − CDM benefits]/annual energy generation in kWh = [1,26,80,000 − 10,56,195]/[1.5 × 1000 × 300 × 24] = Rs. 1.10/-

Cost of generation per kWh without subsidy = Rs. 1.84/-

Cost of generation per kWh with subsidy = Rs. 1.20/-

Cost of generation per kWh with CDM benefits = Rs. 1.10/-

5.4. Comparison of technologies

As it is clear from the Table 23, it is cheaper to use biogas in pure mode in IC engine than biogas in dual mode with diesel. However installed capacity of plant will decrease while we use biogas in pure mode.

6. Conclusion

Energy from waste is not a new concept but it is a field, which requires a serious attention. There are various energy conversion technologies available to get energy from MSW but the selection is based on the physical and chemical properties of the waste. So it is important to go for a detailed analysis of the MSW to choose a right technology.

The MSW of Haridwar city is chemically analyzed in institute's laboratory. Various analysis such as proximate analysis and TGA/DTA analysis has been done to check the chemical properties of MSW and it is suggested that the biomethanation is the best technology for energy conversion. A detailed analysis has been done to check the economic viability of each technology and suggested that using biogas in biogas engine with a 1.5 MW capacity of plant is the best option with cost of generation with & without CDM benefits is Rs. 1.36/- and Rs. 1.41/- per kWh of energy against the energy from grid [Rs. 3.50/- per kWh]. Further it is suggested that use of biogas in IC engine is the second best option with a capacity of 1.8 MW with cost of generation with & without CDM benefits is Rs. 2.72/- and Rs. 2.81/- per kWh of energy against the energy from grid. CDM analysis is also carried out for different technology and it is found that carbon credits achieved in case of using biogas in biogas engine in pure mode is 1820 tonne of CO_2.

Therefore, power generation from MSW of Haridwar city using biomethanation technology is feasible.

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